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G02F

(54) Fibre optic telemetry

(57) A method for converting an electrical signal to an optical signal in an optical fibre comprises applying the electrical signal to piezo-electric transducer in contact with the optical fibre so as to apply an acoustic wave to the fibre. Light passed through the acoustic wave in the optical fibre is modulated at the frequency of the electrical signal. In a network for monitoring the outputs from several sources (1,2...n), each source is connected to a common optical fibre communication channel by means of apparatus for implementing the above method. Each source is arranged to deliver its output signal to the channel as intermittent information packets. Each source is further controlled by means of a pseudo-random number generator such that the source delivers its output signal independently of the other sources at pseudo-randomly varying time intervals.

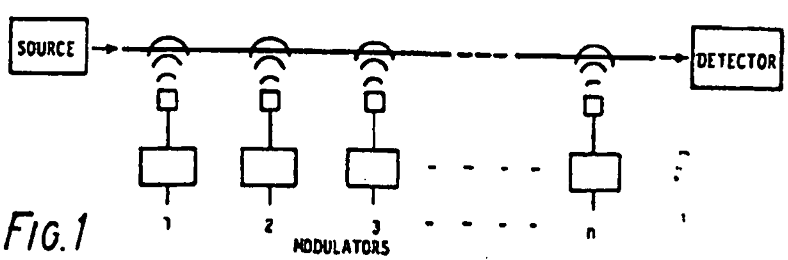

FIG.1

The drawing(s) originally filed was (were) informal and the print here reproduced is taken from a later filed formal copy.

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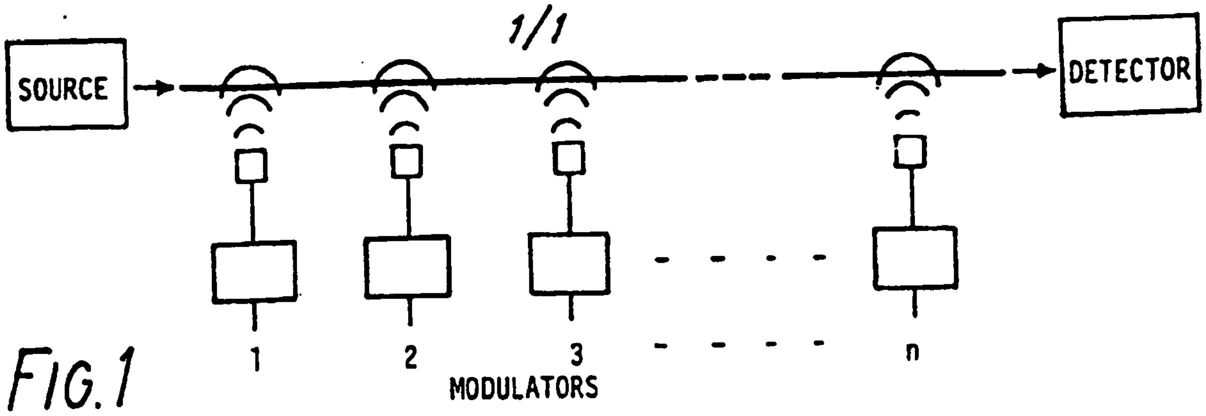

FIG.1

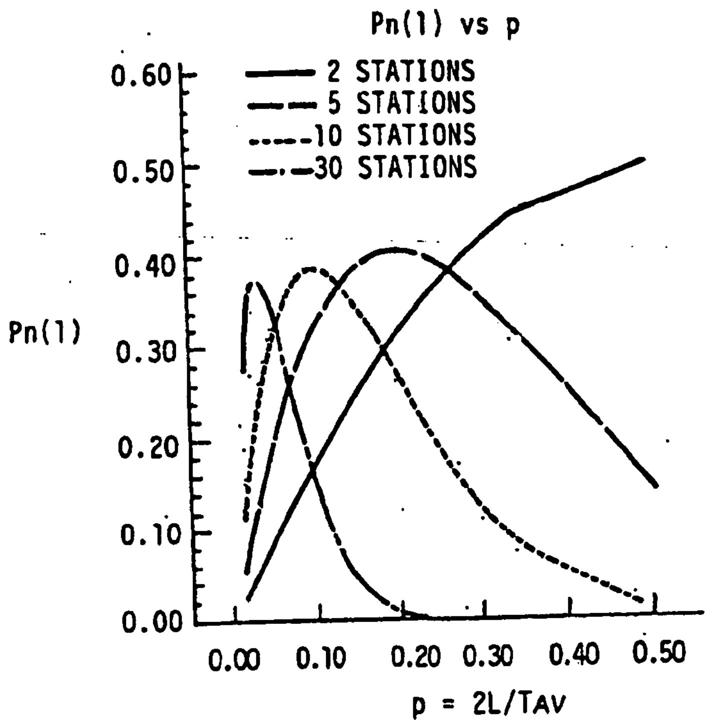

FIG.2

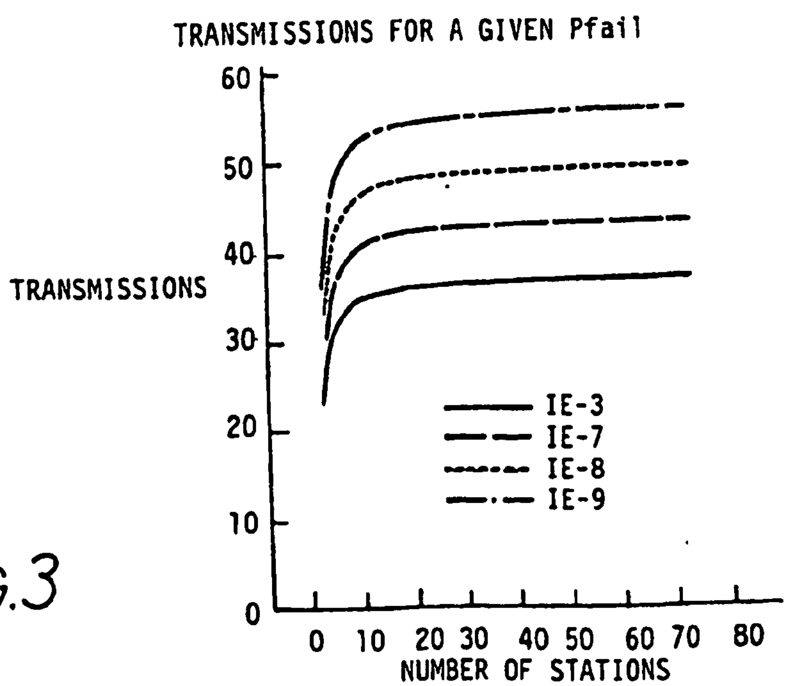

FIG.3

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FIBRE OPTIC TELEMETRY

The present invention relates to improvements in data transmission networks, especially, but not exclusively networks using fibre optics cable. It is also concerned with a system for converting electrical signals into optical signals in a fibre optic cable.

The use of fibre optic for the transmission of telemetry data in instrumentation is of considerable interest due to the significant advantages offered by this particular technology. Primarily the high level of noise immunity and intrinsically safe nature of fibre optic have been the reasons behind this interest although the available bandwidth and distance transmission capabilities have obviously contributed. Hitherto the use of fibre optic in instrumentation systems has largely been confined to the implementation of point to point communication links.

Recent developments in the use in distributed intelligence within instrumentation systems have generally tended to concentrate on the concept of multiplexed signal paths. The concept of a factory-wide data highway forms the basis of many of the current generation of instrumentation networks in existence. Certainly the strongest contenders amongst the emerging standards are based on the principle of a multi-drop bus.

The difficulties associated with realising a multi-drop transmission path would appear to account for the main reason why fibre optics has, to date, not generally been taken up by the instrumentation systems. The principal difficulty would appear to be the problem of tapping into a fibre optic bus. This problem can be subdivided into two distinct areas, firstly the degradation of system performance brought about by the inclusion of a large number of taps in the transmission path and secondly the difficulty of making a connection in a typical instrumentation environment.

The degradation of system performance due to the use of taps is attributable to the fact that it is impossible to introduce a

coupler into a fibre without adding loss. Although the continual improvement in coupler design is gradually reducing the level of insertion loss, the necessity to divert light into each receiving node on a network dictates that a significant attenuation in signal level must ensue. For a typical instrumentation system employing many nodes the problem becomes one of dynamic range in that nodes at opposite ends of a network may well experience vastly differing levels of received signal. The result of this dependency of receiver signal levels on network position detracts significantly from the advantages of using a common data path.

The difficulty of making a connection in many instrumentation environments stems both from the effect of the environment on the task of making a connection and the potential effect on the environment of the connection process. In the former case many instrumentation systems are installed in areas which are not conducive to the attainment of a low-loss connection due to the problems of contamination, for example, coal mines, offshore oil platforms, flour mills. Secondly these environments are often designated as hazardous areas and the use of arc splicing techniques, generally regarded as the best means of achieving a low-loss fibre optic connection, are consequently precluded under the requirements for intrinsic safety.

According to the present invention in a first aspect, there is provided a method for converting an electrical signal to an optical signal in an optical fibre, comprising applying the electrical signal to an electroacoustic transducer coupled acoustically to the optical fibre so as to apply an acoustic wave to the optical fibre, and passing light through the acoustic wave in the optical fibre whereby the light is modulated at a frequency corresponding to the frequency of the electrical signal.

The present invention also provides apparatus for converting an electrical signal to an optical signal comprising an electroacoustic transducer and an optical fibre, the transducer being coupled acoustically to the optical fibre so that when energised by the electrical signal, the transducer applieds an acoustic wave to the optical fibre.

The electroacoustic transducer may be in direct contact with

the optical fibre, or, in the case of a sheathed cable, the transducer may be in contact with the sheath surrounding the optical fibre. Alternatively, the electroacoustic transducer may be coupled to the optical fibre by an incompressible fluid, for example contained in a jacket sealed around a section of the optical fibre.

In use light from a coherent source, for example, a laser, is directed into one end of the fibre optic cable and a detector is arranged to examine the light at the other end of the cable. The cable may be clamped between the crystal of piezo electric modulator and another fixed surface so that when an electric signal is applied to the piezo-electric crystal it compresses the cable transversely at the frequency of the signal. These compressions cause the phase of the light passing through the cable to be altered at the same frequency. The optical fibre should be a multimode fibre. In a multi mode optical fibre the distribution of light intensity across a cross-sectional area of the fibre consists of a pattern of light and dark areas resulting from the interference of the light propagating in the various modes. When the acoustic wave is applied to the optical fibre by the electroacoustic transducer it causes changes in the dimension and refractive index of the fibre at the frequency of the electroacoustic transducer. These dimensional and refractive index changes in the fibre cause different changes in phase of the different modes. As a result, the interference pattern of the transmitted light in the optical fibre will change at the frequency of the modulating signal from the electroacoustic transducer.

If the detector, which may be a photodiode, is located to observe the light at a particular point on the cross-section or on a magnified image of the cross sectional pattern, the light at this point will vary in intensity at a frequency corresponding to the frequency of the electric signal as the pattern of light and dark areas changes at the same frequency as a result of the phase modulation of the modes.

The number of modes is a function of the dimension and refractive index of the fibre in relation to the wavelength of the light in the fibres. If there are too many modes, the interference pattern will not be suitable. There will be too many light and dark

areas and the spacing between light and dark areas will be too small in relation to the size of the detector to produce a satisfactory result. If there are too few modes, the size of the light or dark areas may be so large in relation to the movement of the patern caused by the phase changes, that the detector does not experience any observable change in the intensity of the pattern. It has been found that 5 to 10 modes will produce satisfactory results.

The present invention can thus be used to realise a fibre optic multi-dropped bus utilising an unbroken fibre as the transmission path. The technique employed involves the modulation of light within the fibre using an acoustic wave to vary the characteristics of a multi-mode fibre resulting in a differential phase modulation of the propagating modes. Figure 1 shows a diagrammatic form of the network with the connected nodes individually modulating the fibre via piezoelectric modulators. The resulting variations in phase cancellation and addition of the propagating modes produces an output signal at the detector at the frequency of the modulators. Data from individual modulators may be transmitted as a binary signal using frequency shift keying.

Multiplexing of data from a number of modulators can be achieved using either frequency division multiplexing (FDM) or time division multiplexing (TDM). FDM requires that each modulator employs a different carrier frequency and that the detector filters out each of the utilised frequencies. TDM allows the individual modulators to be identical and obviates the need for configuration dependent filtering usually at the expense of requiring some arbitration method or protocol. Since the system described here does not allow the transmission of data to the connected nodes the use of a two-way protocol is precluded. Instead the method adopted uses the technique of allowing collisions of data to occur on the bus on the basis that they can be detected and the data can be subsequently ignored as invalid. It is immediately apparent that there must be some redundancy in the utilisation of the available channel bandwidth to accommodate the overheads of data validation (in the form of transmitted check codes) and the inevitable loss of colliding data packets.

When two sources simultaneously transmit data to the data bus

it may well transpire that the data from either one of them is not corrupted, although this is unlikely in practice. The technique used does not make any assumption with regard to corruption of this data however since the fact that it has been corrupted will be detected by a violation of check codes appended to the message. If a message is received as valid it will be treated as such regardless of whether it occured simultaneously with another or not. Indeed there is no way of knowing, other than by detecting an invalid message, whether a data collision has occured.

The initiation of transmissions from the connected nodes, or outstations, is achieved on a random basis with each outstation maintaining a pseudo-random number generator which determines the time intervals between transmissions. Each generated pseudo-random number is loaded into a count-down-timer which is then decremented on clock pulses until it reads zero. By this method, pseudo-randomly derived time intervals are obtained with lengths proportioned to the generated pseudo-random numbers. The pseudo-randomly derived time intervals are arranged to have a uniform distribution with an average value given by:

$$T_{AV} = \frac{T_{MAX} + T_{MIN}}{2}$$

A collision occurs if any two data packets of duration L are commenced during a time interval 2L. The probability of a station transmitting within this time interval is given by:

$$P = 2L/T_{AV} \qquad (1)$$

The probability of only one outstation transmitting at a time can be derived from the binomial function using the probability of transmission given in (1) above,

$$P_N(1) = NP(1 - P)^{N-1} \quad (2)$$

where N is the number of connected outstations.

Figure 2 shows a plot of (2) against (1) for systems involving various numbers of outstations. In general it can be shown that P_N is maximised by the situation:

$$P = \frac{1}{N} \qquad (3)$$

Hence the optimum relationship between average transmission interval, packet length and the number of outstations is derived from (1) and (3) as:

$$T_{AV} = 2LN \qquad (4)$$

Thus for a given packet length, T_{AV} can be calculated to optimise system performance according to the number of connected outstations.

Perhaps one of the biggest disadvantages of such a system of data multiplexing however is that there will always be a finite probability of a station being unable to transmit a collision free data packet in any given time period. In practice with a suitable choice of average transmission interval the probability of unsuccessful transmission can be made extremely small. The probabilities of such an occurance are plotted in Figure 3.

The results for system performance quoted thus far have been derived from a computer simulation of the system. A practical implementation using 40 KHz ultrasonic transmitters clamped to a 65 micron core optical fibre with a Helium Neon laser source has been found to suffer significant signal degradation due to variations in the intensity of the light source obscuring the variations in light signal due to the the accoustic wave. However, with a sufficiently stable light source these problems should not arise.

Thus, according to the present invention in another aspect there is provided a network for monitoring the outputs from several sources, comprising a communication channel, each source being arranged to apply its output signal to the channel as intermittent information packets, a detector for receiving information from the channel, and a pseudo-random number generator associated with each source for controlling the time intervals between the information packets from the source, in use, each source delivering its output signal to the channel independently of the other sources at pseudo-randomly varying time intervals. The average time interval between

transmission should be chosen in relation to the length of the data packets and the number of sources that there is an acceptable high probability of data being received from any given transmitter within a specified time. The system is preferably implemented in a fibre optic cable system as described above but it could be implemented in other ways, for example, a copper wire implementation using RS485 differential line drivers with a twisted pair bus.

The invention described above may be used in various applications. It is especially useful in hazardous environments. For example, it may be used to monitor the output from a system of gas detectors deployed in a mine, a petrochemical plant, or on oil rigs. Each gas detector can be connected to the bus and arranged separately with transducing means to issue its output signals to the data bus at random time intervals using independent random number generators to determine the time intervals. The bus may be provided by means of a fibre-optic cable having a light source at one end and a light detector at the other end. The light source and the light detector could be arranged together at the same location, with the fibre-optic cable arranged in a loop that runs past each of the gas detectors.

Although in the network described above the times at which each source transmits its output is controlled by a pseudo-random number generator, the apparatus for converting electrical signals to an optical system in accordance with the invention may be used in a network in which the timing of the output from each source is controlled by other means. For example, each source may have associated with it a separate timing means, each timing means being set relative to the timing means for the other sources in the system according to an established sequence so as to cause each source, in turn, to transmit its output to the optical fibre in a predetermined order. Alternatively the signal sources may be triggered to transmit their outputs by a signal from a central station transmitted by radio signal or other suitable means.

CLAIMS:

1. A method for converting an electrical signal to an optical signal in an optical fibre, comprising applying the electrical signal to an electroacoustic transducer coupled acoustically to the optical fibre so as to apply an acoustic wave to the optical fibre, and passing light through the acoustic wave in the optical fibre whereby the light is modulated at a frequency corresponding to the frequency of the electrical signal.

2. A method according to claim 1, wherein the electroacoustic transducer is a piezo-electric modulator.

3. A method according to claim 1 or 2, wherein the electroacoustic transducer is in contact with the optical fibre.

4. A method according to claim 1, 2 or 3 wherein the light is modulated at the frequency of the electrical signal.

5. A method according to claim 1, 2, 3 or 4 wherein the optical fibre is a multimode fibre, the light being modulated by a change in refractive index and/or dimension of the fibre causing different phase changes in the different modes, the different phase changes causing the interference pattern of transmitted light to vary at the frequency of the acoustic wave.

6. A method according to any of the preceding claims including detecting the optical signal by observing the intensity of light at a point on the cross section of the cable.

7. An apparatus for converting an electrical signal to an optical signal comprising an electroacoustic transducer and an optical fibre, the transducer being coupled acoustically to the optical fibre so that when energised by the electrical signal, the transducer applieds an acoustic wave to the optical fibre.

8. An apparatus according to claim 7, wherein the electroacoustic transducer is a piezo-electric modulator.

9. An apparatus according to claim 7 or 8, wherein the electroacoustic transducer is clamped to the optical fibre.

10. An apparatus according to claim 7, 8 or 9, wherein the optical fibre is a multi-mode optical fibre.

11. A method of time-division multiplexing of a plurality of signals comprising sampling the signals and transmitting each signal as a packet at a pseudo-random time interval, independently of the other signals, through a common communication channel.

12. A network for monitoring the outputs from several sources, comprising a communication channel, each source being arranged to apply its output signal to the channel as intermittent information packets, a detector for receiving information from the channel, and a pseudo-random number generator associated with each source for controlling the time intervals between the information packets from the source, in use, each source delivering its output signal to the channel independently of the other sources at pseudo-randomly varying time intervals.

13. A network according to claim 12, wherein the communication channel comprises a data bus.

14. A network according to claim 12 or 13, wherein the time intervals are determined so as to be proportional in magnitude to the numbers generated by the pseudo-random number generator.

15. A network according to claim 14, wherein a number generated by the pseudo-random generator is processed by a count-down-timer to effect a time interval.

16. A network according to any of claims 12 to 15, wherein the

numbers are distributed statistically about a predetermined average value.

17. A network according to claim 16, wherein the numbers are distributed uniformly about the predetermined average value.

18. A network according to claim 16 or 17, wherein the average value is selected, with respect to the number of the sources in the network and the length of each information packet, to maximise the probability that at any particular moment, one sensor will be sending an information packet and the remaining sensors will not.

19. A network according to any of claims 12 to 18, wherein the communication channel is provided by means of an optical fibre.

20. A network according to claim 19, wherein each source is connected to the optical fibre by means of the apparatus of any of claims 7 to 10.

21. A network according to claim 19 or 20, wherein the optical fibre has one end connected to a light source, and the other end connected to the detector, the light source and detector being located next to one another and the optical fibre being arranged in a loop that runs past each of the sources.

22. A network according to claim 21, wherein the network is arranged in a mine and each source comprises a remotely located gas sensor.

23. A method for converting an electrical signal to an optical signal substantially as hereinbefore described.

24. An apparatus for converting an electrical signal to an optical signal substantially as hereinbefore described.

25. A network substantially as hereinbefore described with reference to the accompanying drawings.